# The importance of lidar in shaping the future of wind energy

Lidar technology has come a long way since NASA first used it during 1971's Apollo 15 mission to the moon. Modern lidar systems have applications across many industries, and they are being used extensively by the wind power industry for both current and emerging onshore and offshore applications. Matthieu Boquet, Head of Market and Offering, Wind Energy for Vaisala, explores the potential for this technology in the future.

From research and development all the way through to post-construction operation and monitoring, lidar can be easily integrated into any stage of a project, including planning, funding, surveying, construction, assessment, monitoring and optimization. Due to advances in remote sensing technology and the numerous advantages that come with it, these systems are quickly replacing or co-existing with traditional masts on wind projects across the globe.

Lidar is also mobile and with a small footprint that is not disruptive to the landscape or the environment, so systems can be deployed rapidly, safely and with great flexibility. As a result, it can be used temporarily if needed for only one stage of a wind project, and then easily repurposed for other stages or projects.

Most importantly, lidar is also more reliable than ever before, offering unmatched accuracy, range and depth of data, even as turbines continue to increase in size or terrains get more complex.

As the technology advances, lidar is rapidly becoming the industry standard for the accurate measurement of wind, with deployment at thousands of sites and millions of hours of operation in the field.

While there are numerous examples of lidar's success and opportunity, here are a few examples highlighting new innovations and use cases for lidar, including an innovative floating wind farm off the coast of Scotland, an impressive global project designed to assess the blockage effect and a new approach to wind measurement in complex terrain environments.

**Floating offshore wind farm: Hywind Scotland**

The collaborative project between Equinor and IFP Energies Nouvelles (French Institute of Petroleum) helped push the use of lidar into deeper waters at Hywind Scotland, the world's first commercial wind farm to use floating wind turbines.

The joint venture utilized a time-domain turbulent 4D wind field generator that uses lidar to measure wind speed at the site, with the ultimate goal of creating standards for accurate measuring of loads, fatigue and power.

Floating turbine designs are relatively new, and so are their challenges, including Power Performance Testing (PPT) and load calculation. To accurately measure wind properties at Hywind, project developers need to retrieve wind properties that are available and accurate. These include horizontal wind speed, rotor averaged wind speed, turbulence intensity or shears. They also require wind properties that are already compensated from the induction zone, from the nacelle-induced motions and with turbines with constantly growing rotor sizes.

These measurements can help overcome issues such as the Cyclops effect, blade blocking and the wind behavior changes that occur as the wind approaches the rotor. In addition, they have to handle the technology related spatial filtering effect, to retrieve as best as possible the wind spectrum bandwidth that is harmful to the structures.

Moreover, with floating designs, inducing noticeable nacelle motions, translations and rotations, comes a necessity to localize the lidar measurement locations at each sample time. To achieve that, a Motion Record Unit (MRU) set up in the nacelle is used in combination with adapted processing to accurately provide the radial wind speeds measurements and locations.

In this context, IFPEN developed, in collaboration with Equinor, a solution that can estimate the incoming full wind field, based on the lidar measurements and the MRU outputs, thanks to a three step algorithm.

First, a motion compensation step identifies and handles the changing lidar positions and lines of sight induced by the nacelle displacements. This enables an estimate in the second step, a full space and time grid of wind vectors, through an Information Kalman Filter-based approach. This result leads to the final step: the wind velocity vectors at the rotor plane are obtained.

In summary, combining pulsed lidar sensing technology with adapted processing of raw data and MRU quantities can provide a reconstruction of highly accurate wind information, including hub-height wind speed, rotor-averaged wind speed, turbulence intensity and wind direction.

The wind energy sector can expect this development to improve both the representativeness of loads and fatigue computations, and the precision of wind properties used as input for power performance testing applications.

Thanks in part to this innovative application of lidar technology, this 30-megawatt floating wind farm now consistently has the highest capacity factors in the UK. Capitalizing on the success of the Scotland project, Equinor is also in the process of building the world's largest floating wind farm, the 88-MW Hywind Tampen, in the Norwegian North Sea.

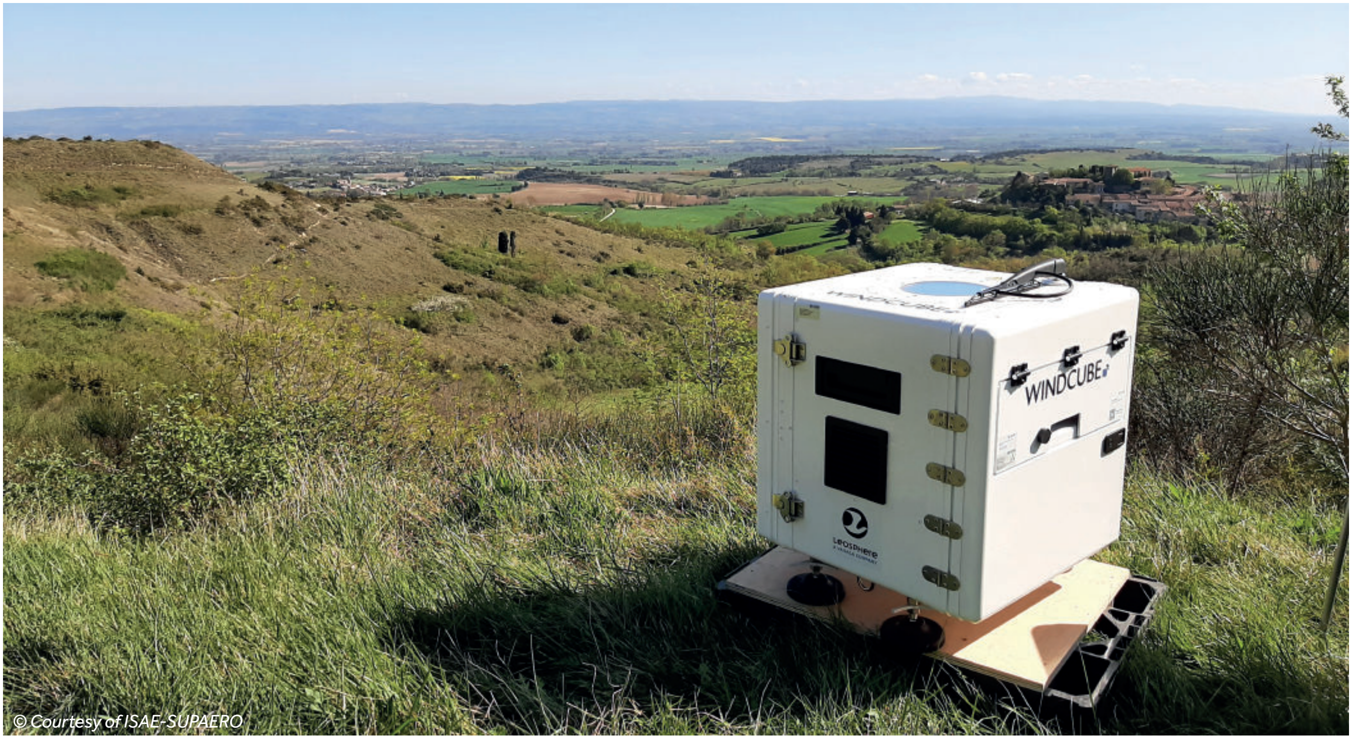
**Offshore wind accelerator global blockage effect initiative**

The Global Blockage Effect in Offshore Wind (OWA GloBE) initiative is another project utilizing lidar applications that are considered to be especially innovative.

The Global Blockage Effect (GBE) is a phenomenon that occurs with offshore wind farms regarding the interaction between the wind farm and the atmosphere. When the wind hits an offshore wind farm, the flow naturally slows down, diverting around the turbines and creating a blockage effect that is very subtle and difficult to measure.

In early 2021, a group of offshore wind developers joined forces, under the umbrella of Carbon Trust's Offshore Wind Accelerator, to improve the understanding of GBE impact. Led by RWE Renewables, the group's goal was to try to better understand the flow, measure it more precisely and learn how to improve the design of future wind farms. They also wanted to produce a dataset that could be adopted as the industry benchmark for quantifying the impact of the GBE on energy production.

At the three wind farms, the campaign uses a combination of various measurement devices, including six scanning lidars in a




WindCube v2.1 in complex terrain


Scanning lidar

three dual lidar set up. The scanning lidar hard target calibration process can be challenging in an offshore environment with limited infrastructure.

Since offshore platforms tend to tilt and move due to the vibrations and thrust of the turbines, the team proposed a new method for calibrating and verifying the scanning lidar beam position: using a drone as a movable, controllable hard target. Rather than putting up a mast or installing objects that would be visible from each position, researchers flew the drone into position, using the drone itself as the target, similar to how physical objects are mapped onshore.

To understand the pitch and roll of the system at high frequency throughout the experiment, one technician flew the drone right into the path of the lidar beam, while another monitored the measurements in real time to improve the accuracy of its position.

They then combined the drone and lidar data and used a carrier-to-noise ratio (CNR) filter to confirm the exact times when the drone was hit by the lidar beam. The team was able to determine an alignment, both in the azimuth and the elevation, for each axis, successfully demonstrating how to calibrate scanning lidars using drones as a controllable hard target in offshore environments.

## Estimating terrain complexity

Wind farms are increasingly moving to the mountains, foothills and other complex terrain areas. In order to create bankable reports for projects in these complicated environments, lidar measurements require post-processing corrections.

For example, WindCube® lidar has been used in moderately complex terrains for many years, thanks to integrated and patented Flow Complexity Recognition (FCR) software. Now, through strategic partnerships, WindCube measurements can be used in even more complex terrains using the proven Computational Fluid Dynamics (CFD) correction method.

Additionally, Vaisala introduced a lidar-powered terrain complexity estimator tool to estimate wind speed biases throughout complex terrain sites, empowering project owners to better optimize measurement campaigns, planning for a mixture of FCR algorithm, CFD and met masts, based on budget and the specific wind resources at the site.

Users feed elevation model data, which utilizes a neural network trained on thousands of lidar simulations in complex terrain to create input and output nodes based on pixels from the elevation map and the wind speed error rate at a particular height in a particular direction.

By combining the directional errors with annual wind roses from that particular location, it is possible to estimate the complex flow-induced long-term wind speed error for a specific site. Leveraging this tool to estimate wind speed biases throughout complex terrain sites enables optimized measurement campaigns.

## Lidar is setting the standard for future success

With each successful application of lidar in the wind industry, the key players continue working on even more improvements to the technology. As necessary guidelines and standards evolve to create confidence for stakeholders around the globe, lidar will only become increasingly integral for any future wind energy project.

From scanning lidar calibration using drones offshore to combining inertial measurements with nacelle lidar data at floating wind farms to estimating possible complex flow lidar error corrections, it's essential to recognize how lidar technology is driving innovation and propelling the wind energy industry forward.

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**Biography**

Matthieu Boquet is Head of Market and Offering, Wind Energy for Vaisala. In this role, he drives WindCube® lidar offerings to meet the industry's high-level expectations while helping customers continually generate value from their lidars.